Conceptual Models as a Tool for Assessing, Restoring, and Managing Puget Sound Habitats and Resources

Ronald M. Thom, Gregory D. Williams *and* ***Amy B. Borde***
Battelle Marine Sciences Laboratory, Pacific Northwest National Laboratory

Abstract
The City of Bainbridge Island is conducting a seminal nearshore characterization and assessment project funded through the Salmon Recovery Funding Board. The primary objective of this effort is to provide baseline data upon which to develop and implement nearshore management strategies (including restoration and preservation) and measure management success. A science-based conceptual framework was used to characterize the status of shoreline ecological functions based upon systematic evaluations of shoreline modifications, controlling factors, habitat structure, and habitat processes. Approximately 48.5 miles of shoreline was broken down into nine management units (based on drift cell knowledge) and each unit was analyzed by reach (based on the WADNR ShoreZone Inventory). Digital data, including the Bainbridge Island Nearshore Structure Inventory, was quantified using GIS which was in turn used to conduct a qualitative (3-tier) assessment using defensible, systematic matrices. The qualified measures were based on quantified parameters derived from the literature, current and historical shoreline photos, and expert opinion. This information was synthesized to determine human impacts, locating critical areas for protection or restoration, and identifying nearshore ecosystems most at risk to cumulative impacts. Based on readily available or easily collectable data, this approach could provide a useful framework for similar assessments in Puget Sound.

Introduction
The purpose of our paper is to describe our approach to the development and application of conceptual ecological models in assessing and restoring estuarine and nearshore ecosystems in the Pacific Northwest. Factors that control the abundance and dynamics of habitats and resources are often not quantitatively understood. Conceptual models (e.g., box and line diagrams) are one useful method of organizing information on those factors that control habitat and resource dynamics. These models can be used to facilitate habitat monitoring, restoration, and ecosystem management. Two decades ago, the Chesapeake Bay National Estuary Program developed a simple model that has guided the monitoring program and driven restoration actions valued at millions of dollars (Dennison *et al.* 1993). More recently, large ecosystem restoration programs in the Mississippi River delta and Florida Everglades have also incorporated conceptual models (Gentile *et al*. 2001). Organizing our understanding in a graphic but simple way can assist in understanding, restoring and managing nearshore ecosystems in the region. We argue that if we cannot organize an understanding of the ecosystem, we have little basis for managing or restoring the system.

According to Huggett (1993), a conceptual model expresses ideas about components and processes deemed to be important in a system, and some preliminary thoughts on how the components and processes are connected. They help to clarify loose thoughts about how a system is composed and how it operates. We have found that explicitly expressing our understanding of the organization of a system leads to consensus among individuals, clarifies assessments of impacts from development projects, helps in the design of restoration projects, and assists in making management decisions. The models also highlight uncertainties in our knowledge base, and point toward critical research needs.

In 2001, we developed a conceptual model for the Columbia River estuary to help trace the impacts of the proposed navigation channel deepening on juvenile salmon and other resources. In Puget Sound, we are currently employing a conceptual model to help improve eelgrass restoration and to understand the effects of shoreline development on nearshore marine habitats. In addition, we are using conceptual models to drive management decisions regarding shoreline development (Williams and Thom 2001). The models present a logical, science-based method for evaluating potential multiple stressors on coastal ecosystems, planning restoration projects and refining a practical monitoring program, incorporating lessons learned, and communicating information on the programs to the public.

Basic Model
The basic model we employ consists of three elements: **controlling factors, ecosystem or habitat structure, and ecosystem or habitat function**. The premise of the model is that controlling factors (e.g., hydrology, elevation, sediment type, wave energies) result in the development of the habitat structure (i.e., the species and their abundance). In addition, once the habitat structure is developed, the functions (e.g., primary production, food web support, fish and invertebrate rearing and reproduction, organic matter export) normally associated with that structure would be supported. For Puget

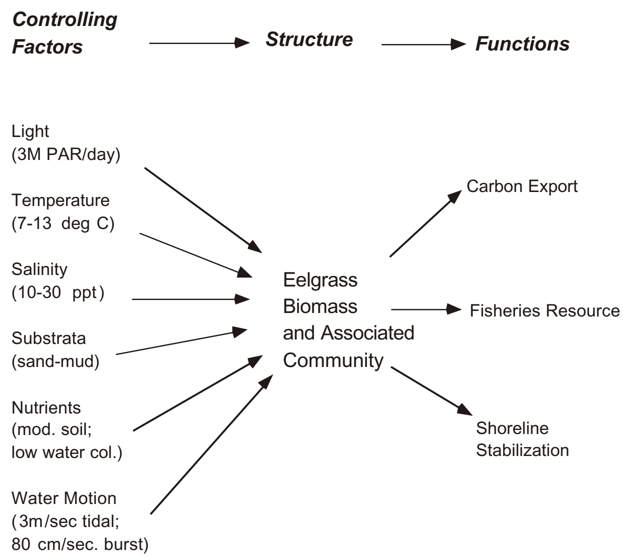

Figure 1. Conceptual model for eelgrass.

Sound, we have two excellent examples supporting this simple model. First, the Puget Sound Habitat Assessment Protocol (Simenstad et al. 1991) provides the scientific underpinning linking habitat types with the fish, bird and invertebrate species they support. The Protocol summarizes our basic understanding of which species occur in what habitats and why (i.e., feeding, rearing, reproduction, transit, etc.). Second, the habitat classification system (Detheir 1990) for nearshore and estuarine environments defines the physical (wave energies, elevations, geomorphological) conditions within which various habitat types occur. The habitat classification system relates controlling factors to habitat structure, and the protocol relates habitat structure to key functions supporting aquatic-dependent resources.

The Eelgrass Model

Eelgrass (*Zostera marina* L.) fringes the shallows of Puget Sound and the Straits of Georgia, as well as many areas in the Georgia Basin. There is clear evidence that this habitat provides support for a multitude of species (Phillips 1984; Simenstad et al. 1991). Development pressure and modifications of the shoreline have resulted in impairment and loss of eelgrass (Williams and Thom 2001), and restoration of eelgrass is being carried out. Because of common failures in eelgrass restoration along the west coast (Thom 1990), there is considerable uncertainty regarding the potential to restore eelgrass. Through a series of research efforts, we now have a refined understanding of the physical and chemical requirements of eelgrass (Thom et al. in review). These requirements are summarized in the conceptual model illustrated in Figure 1. The model summarizes the range of values for controlling factors needed, at a minimum to support eelgrass growth.

Light is a key factor, and research is showing that at a minimum eelgrass needs about 3M of photosynthetically active radiation (PAR) per day during spring and summer to survive through winter (Thom *et al*., in preparation). Full growth requires up to 7M per day. Using the information on controlling factors, we have been assessing the potential for sites in Puget Sound to support eelgrass, and thus where to recommend eelgrass restoration. The model also helps us assess factors responsible for the loss of eelgrass. We have used the model to help explain why eelgrass transplants in a marginally adequate site in Eagle Harbor on Bainbridge Island, did not survive. Here, high temperatures, coupled with algae blooms caused by a strong El Niño event in 1997-1998 killed the transplants (Thom et al. 2001).

Columbia River Estuary Model

Driven by the economic need to deepen the navigation channel by 3 feet in the Lower Columbia River and estuary and concerns regarding the effects of the project on juvenile salmon, an extensive evaluation was conducted of the environmental effects of this action. To assist in evaluation of effects, a conceptual model was developed that focused on the growth and survival of juvenile salmon. The model allowed those debating the impacts to evaluate the most likely paths of impacts, as well as weed out those pathways that were irrelevant. The habitat forming processes submodel (Figure 2) of the ecosystem model identified the primary factors affecting the formation and maintenance of habitats in the ecosystem. The degree and level of these processes defined what habitats occurred where and what might control

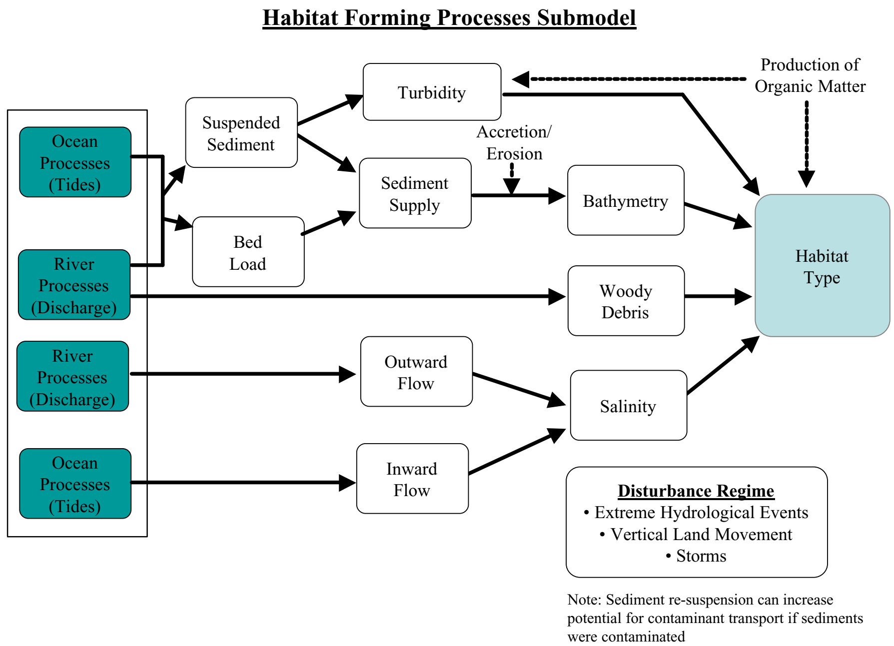

Figure 2. Habitat forming processes submodel of the Lower Columbia River and estuary ecosystem model.

their variation in time. Although simplistic, this model clearly and explicitly identifies that alterations of bathymetry, as related to dredging, may affect habitat types depending on the degree of alteration. From this point, those assessing impacts discussed the potential for, and degree of, alteration.

The Lower Columbia River and estuary was historically subjected to periodic and massive disturbances because of flood flows. With flow regulation at the dams, disturbances of this type have decreased in magnitude and frequency. The historical flooding was very effective in structuring the biological communities, and likely the ecological processes in the system. This river-dominated system could go from a typical estuary with a well developed mixing zone to one totally dominated by freshwater outflows. The mixing zone is referred to as the estuarine turbidity maximum (ETM) and has been shown to be an important location for flocculation of organic matter, nutrient cycling, and deposition of organic and inorganic matter (Simenstad et al. 1994). Thus, changes in the location and dynamics of the ETM by deepening the channel could upset the ecology of the present-day estuary. To capture this dynamic, a disturbance submodel was developed (Figure 3). Flow regulation has essentially rendered the estuary "more stable." This stability is artificially induced, and if restoration of the estuary to pre-flow regulation conditions were done, the system would be come naturally less stable. Put another way, the system would exhibit a wider dynamic equilibrium state. The effects of this change are speculative relative to the processes and resources utilizing the system.

Nearshore Restoration Strategy Model

The above examples of conceptual models assist in identifying factors to consider in developing restoration plans for estuaries and nearshore systems. To achieve successful restoration of nearshore habitats in Puget Sound, the optimal strategy for each potential restoration site needs to be specified. The models make explicit overarching principals that can be used to guide restoration of nearshore systems in the Sound. We believe that by clearly articulating the potential restoration strategies and the potential sources of failure can help increase the probability of restoration project meeting its goals.

Restoration Strategies

Shreffler and Thom (1993) found, through a review of the literature, that there are five major "restoration" strategies. These five fundamental strategies are designed to improve functions of nearshore systems:

- **Creation**—bringing into being a new ecosystem that previously did not exist on the site (NRC 1992). In contrast to restoration, creation involves the conversion of one habitat type or ecosystem into another.

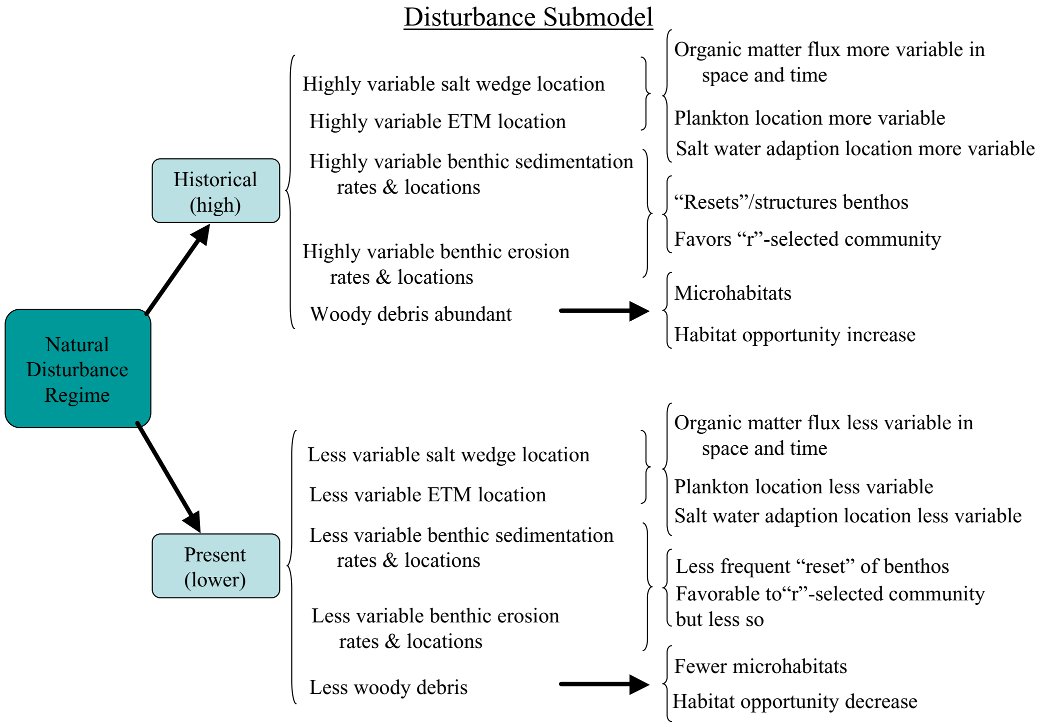

Figure 3. Habitat disturbance submodel of the Lower Columbia River and estuary ecosystem model.

- **Enhancement**—any improvement of a structural or functional attribute (NRC 1992). Shreffler and Thom (1993) found that, for estuarine systems, enhancement often meant *enhancement of selected attributes* of the ecosystem such as improving the quality or size of a tidal marsh or eelgrass meadow.
- **Restoration**—the return of an ecosystem to a close approximation of its previously existing condition (NRC 1992). Restoration involves doing *something* to increase the rate of recovery over the rate of natural recovery occurring without human intervention.
- **Conservation**—the maintenance of biodiversity (Meffe *et al.* 1994). Conservation can allow development to occur as long as biodiversity and the structure and processes to maintain it are not affected.
- **Protection**—the formal exclusion of activities that may negatively affect the structure and/or functioning of habitats or ecosystems. It can also refer to protection of a species or group of species through management actions such as elimination of harm to a species directly or indirectly through damage of its habitat.

Influence of Disturbances

Using the findings of the National Research Council and a review of the literature on estuarine habitat restoration, Shreffler and Thom (1993) found that the strategies of restoration, enhancement and creation should be applied depending on the degree of disturbance of the site and the landscape (Figure 4). It is assumed that the historical conditions represent the optimal habitat conditions for a particular site. In general, restoration to historical conditions is best accomplished where the sites and the landscape are not heavily altered (Shreffler and Thom 1993; NRC 1992). Creation of new habitat (i.e., habitat not historically present) at a site is often done when the site and the landscape are heavily damaged. In situations where the nearshore and adjacent uplands has not been heavily urbanized, the goal of restoring the nearshore habitats to historical conditions is possible. However, sites with a high degree of disturbance on both scales, in general have a low probability for restoration. Creation of a new habitat or ecosystem or enhancement of selected attributes would be the only viable strategies to apply in these situations. In contrast, where the site and landscape are essentially intact, restoration to historical (i.e., humans present, but insignificant disturbance) or pre-disturbance (i.e., before man) conditions would be viable options.

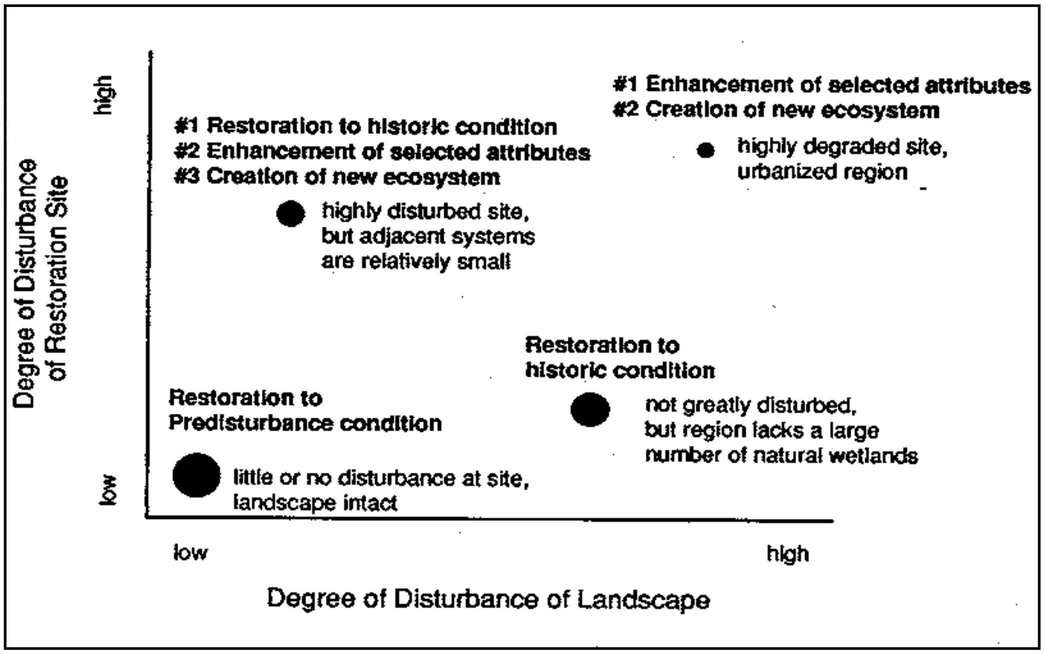

Figure 4. The restoration strategies for nearshore systems relative to disturbance levels on the site and in the landscape (from Shreffler and Thom 1993). The relative chance of success increases with the size of the dot.

Effectively achieving the goal may require that several strategies be employed at a site and/or in the landscape. It is possible that protection of landscape features, enhancement of selected nearshore attributes, and conservation (science-based engineering design) in the nearshore may be highly effective in restoring the ***controlling factors*** which affect historical structure, functions and processes to the system.

Prioritizing Sites for Restoration

There is no universally accepted method for setting priorities for nearshore sites for restoration or for determining what strategies are best applied to each site. We have found that **restoration of controlling factors is the key to successful and long-term restoration** (see Figure 1). Prioritization of sites and restoration strategies for these sites is accomplished by using information designed to reduce uncertainty as much as possible (see Williams et al. 2003). The Department of Natural Resources has developed a continuous data set on habitat types and areas of disturbance for the entire nearshore of Puget Sound. Sections of the shoreline are broken into reaches (varying in length), which represent relatively homogeneous stretches of habitat. A reach forms a easily identified and delineated equivalent to a site. The landscape is represented by drift cells, which are areas of shoreline where sediment is produced, deposited or lost from the system. The process of sediment erosion, transport and deposition is a key process (i.e., controlling factor) forming habitats on Puget Sound, and which has been altered by human development actions.

The matrix in Figure 5 identifies the strategies most appropriate under the nine states of reach and drift cell disturbance. Figure 5 integrates the restoration strategies in Figure 4 and the two additional strategies of conservation and preservation. In addition, the matrix includes a “strategy” of *restricted development*. This refers to locations where disturbance is already moderate to high, as in heavily urbanized estuaries, and development using established environmental regulations is followed. Restricted development would also include other strategies to avoid and minimize further disturbances following general conservation and restoration ecology principles.

High Reach Disturbance	Restore Enhance Create	Restricted development Enhance Create Restore	Restricted development Enhance Create
Moderate Reach Disturbance	Enhance Restore Preserve	Conserve Enhance Create Restore	Restricted development Enhance Create Restore
Low Reach Disturbance	Conserve Preserve Restore	Conserve Enhance Restore	Enhance
	Low Drift Cell Disturbance	**Mod. Drift Cell Disturbance**	**High Drift Cell Disturbance**

Figure 5. Matrix of habitat action strategies most appropriate for the degree of disturbance of the management unit and the reach.

Multiple strategies are potentially viable under any one of the nine system "states." This matrix provides general guidance as a first approximation of specific management actions that could be evaluated within a reach or drift cell. In developing the matrix in Figure 5, the following logic was used:

- The lower the disturbance on both scales, the greater reliance on preservation, conservation, and restoration.
- The greater the disturbance on both scales, the greater reliance on enhancement.
- Under the greatest levels of disturbance, the greater the reliance on creation and restricted development.

This "conceptual model," which is actually a set of matrices, organizes process-based principals to determine potentially successful restoration strategies, and may be a way to identify sites with the highest potential for restoration. For example, sites (reaches) that fall in the upper right box, have a high need for restoration, but according to Figure 4 they have the lowest probability of working. Restoration of the sites would require a substantial effort. In contrast, sites falling into the lower left box are probably in relatively good condition as is the landscape in which they reside. Thus restoring these sites would work but the incremental increase in ecological benefit achieved may be low. Obviously, how sites are quantitatively placed within the matrix is the subject for intense scrutiny and analysis based on data from the site and the region.

Conclusion

Conceptualizing ecosystems provides an opportunity to capture the scientific understanding of the systems on paper. The process of developing conceptual models is often difficult and time consuming, but has proven valuable to us in understanding how systems work, highlighting uncertainties about the systems that can drive research, and clearly delineating appropriate ways to restore systems. In our view, restoration should not proceed without the benefit of a conceptual model and the process used to develop it.

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